

# Executive summary

The MINOS (Main Injector Neutrino Oscillation Search) experiment is designed to search for neutrino oscillations with a sensitivity significantly greater than has been achieved to date. The phenomenon of neutrino oscillations, whose existence has so far not been proven convincingly, allows neutrinos of one “flavor” (type) to slowly transform themselves into another flavor, and then back again to the original flavor, as they propagate through space or matter. The MINOS experiment is optimized to explore the region of neutrino oscillation “parameter space” (values of the  $\Delta m^2$  and  $\sin^2(2\theta)$  parameters) suggested by previous investigations of atmospheric neutrinos: the Kamiokande, IMB, Super-Kamiokande and Soudan 2 experiments. The study of oscillations in this region with a neutrino beam from the Main Injector requires measurements of the beam after a very long flight path. This in turn requires an intense neutrino beam and a massive detector in order to have an adequate event rate at a great distance from the source.

If neutrinos do oscillate, as is suggested by some experimental results and by theoretical extensions of the Standard Model of particle physics, then they will change their flavor as they move through space or matter. Different flavors of neutrinos (electron, muon, tau or sterile) can be identified by the distinctively different patterns of secondary particles they produce when they interact with matter in a massive neutrino detector. Thus an optimum, and most sensitive, way to detect such oscillations is to compare the patterns of their interactions (characterized by topology and energy deposition) at two widely separated locations in a neutrino beam. This technique requires, first, that the beam flavor composition and other characteristics are very similar at these two detector sites, in the absence of oscillations (accelerator neutrino beams consist mainly of muon neutrinos). Second, the two detectors must be identical in their important features. If these two conditions are met, then systematic effects will be minimized by comparing the patterns of interactions in the two detectors, and maximum sensitivity will be achieved. The MINOS experiment design is based on this technique; the technical challenge for the experiment is to build an appropriate neutrino beam and appropriate detectors.

The neutrino beam line proposed for the MINOS experiment will be constructed as part of the Fermilab NuMI Project, which is described in Reference [1]. It relies on the 120 GeV proton beam from the Main Injector, which produces pions and kaons which are then allowed to decay in flight along a 675 m long decay pipe. The neutrinos which constitute the MINOS beam are produced when these pions and kaons decay. The two MINOS detectors are located at Fermilab (the “near detector”) and in the Soudan mine in Soudan, Minnesota, 730 km away (the “far detector”). The existing Soudan cavern will be supplemented by a new, adjoining, cavern to be excavated as part of the NuMI Project; the new cavern will house the MINOS far detector. The work associated with the new cavern excavation and outfitting is described in Reference [2].

The proposed MINOS detectors are iron-scintillator sandwich calorimeters, with toroidal magnetic fields in their thin steel planes. The combination of alternating active detector planes and magnetized steel absorber planes has been used in a number of previous neutrino experiments. The MINOS innovation is to use scintillator with sufficiently fine transverse

granularity (4-cm wide strips), so that it provides both calorimetry (energy deposition) and tracking (topology) information. The 5,400 metric ton MINOS far detector is also much more massive, and potentially more expensive, than previous experiments. Recent advances in extruded scintillator technology and in pixelated photomultipliers have made such a detector feasible and affordable for the first time.

This Technical Design Report describes the main components of the MINOS detectors: the toroidal magnet, the scintillator strips, and the readout electronics, as well as the installation procedures at the Fermilab and Soudan sites. Section 3.2 summarizes the physics goals of the experiment and the properties of the detectors we have designed to reach those goals. The baseline detector design is the basis for the experiment cost estimate and schedule presented in Reference [3]. Since the design of MINOS allows for potential future modifications, in response to developments in neutrino physics and detector technology, we also describe briefly some of these possibilities even though they are not included in the current scope of the project. The capability of the NuMI facility and the MINOS detector to respond to new results from other oscillation experiments is addressed in Reference [4].

Environmental, Safety and Health issues for the Project at the Fermilab and Soudan experimental sites are described in detail in References [5] and [6].

The MINOS experiment described in this TDR is based on a far detector composed of two identical 2,700 metric ton supermodules. The scope of the baseline detector has been defined to be compatible with the funds currently believed to be available for its construction. It is possible that funds from the project scope reserve and from the present contingency pool may become available as the uncertainty in the cost estimate is reduced in the future. It is also possible that additional funds from overseas collaborators could become available. If this should turn out to be the case, it may be possible to construct an additional supermodule (the Soudan cavern dimensions have been chosen to allow for this possibility) or some alternative augmentation of the experiment (such as an emulsion detector at Soudan). This decision about the best use of any such funds would of course take into account current knowledge of neutrino oscillation physics, detector technology and more reliable detector cost estimates.

# Bibliography

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- [3] The Fermilab NuMI Project Staff, “NuMI Project Cost and Schedule Plan,” October 1998, Fermilab report NuMI-362.
- [4] The MINOS Collaboration, “Neutrino Oscillation Physics at Fermilab: The NuMI-MINOS Project,” May 11, 1998, Fermilab report NuMI-L-375.
- [5] The Fermilab NuMI Project Staff, “NuMI Project at Fermilab: Preliminary Safety Assessment Document,” October 1998, Fermilab report NuMI-361.
- [6] The University of Minnesota, CNA Consulting Engineers, Ericksen-Ellison Associates, Inc., and Miller-Dunwiddie, Inc., “MINOS Far Detector Laboratory Project, Preliminary Hazard Assessment Report,” October 1998, Fermilab report NuMI-L-419.